



Cloud Properties for Partly Cloudy Pixels: Consistency Checks and Implications

J.A. Coakley, Jr. and W.R. Tahnk
Oregon State University

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Goal: Quantify biases in fractional cloud cover, effective radius, cloud liquid water, cloud altitude, TOA and surface radiative fluxes, etc. that arise through neglect of partial cloud cover when retrieving cloud properties.

Retrieval Method

Retrieval scheme follows Arking and Childs (1985)

- For single-layered cloud systems, identify overcast pixels and determine altitude of cloud layer.
- For each pixel, radiances are given by

$$I = (1 - A_C) I_S + A_C I_C(z_C)$$

A_C = Fractional cloud cover within a pixel

I_S = Average cloud-free radiance within a pixel

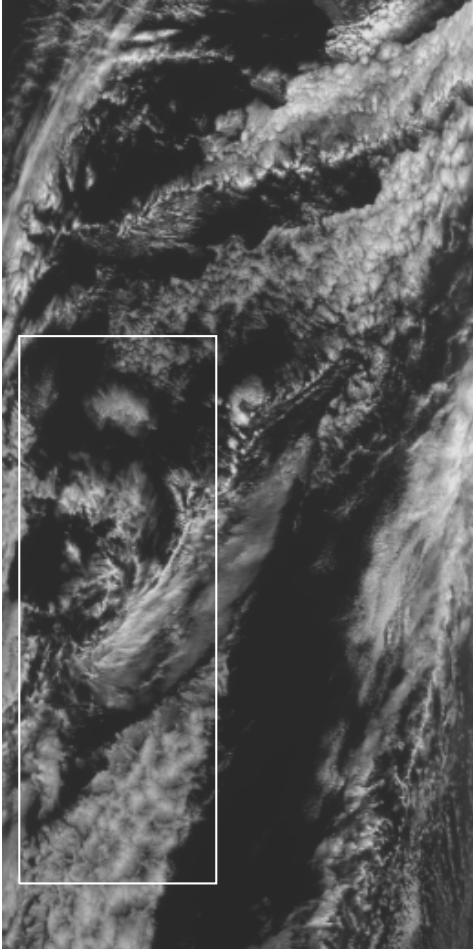
$I_C(z_C)$ = Average overcast radiance within a pixel

z_C = Average cloud altitude obtained from nearby overcast pixels.

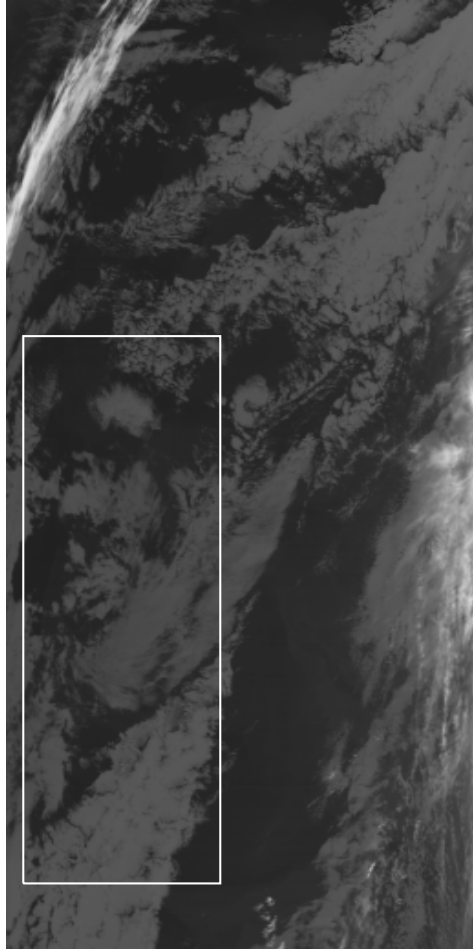
- For each pixel, adjust A_C , τ , R_e so that calculated radiances at 0.64, 3.7, and 11 μm match those observed.

Characteristics of Partly Cloudy Pixel Retrievals

0.64 μm



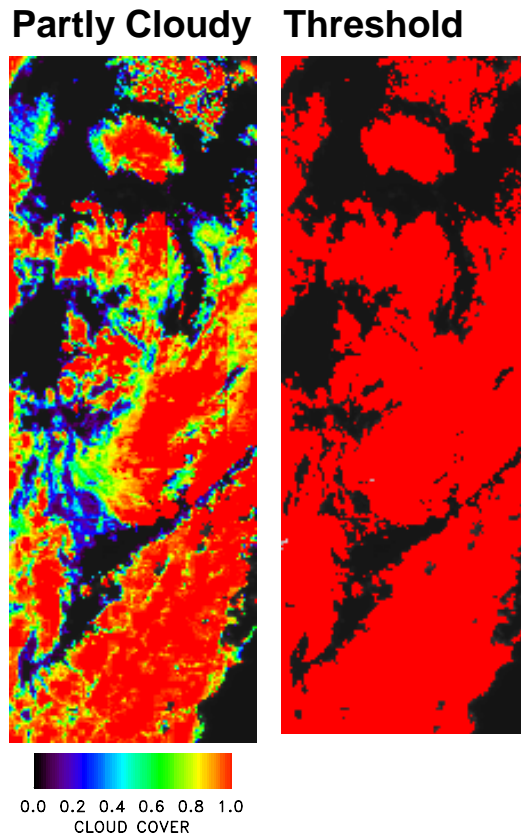
11 μm



- 2-km VIRS imagery off the coast of Australia.
- Boxed region contains single-layered cloud system, $300 \text{ km} \times 630 \text{ km}$ and contains roughly equal numbers of cloud-free and overcast pixels.

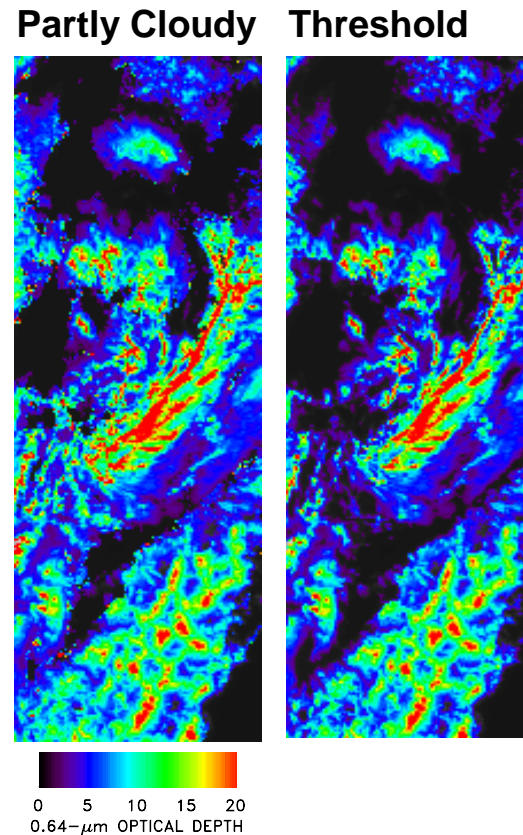
Comparisons with Threshold Retrievals

Cloud Cover



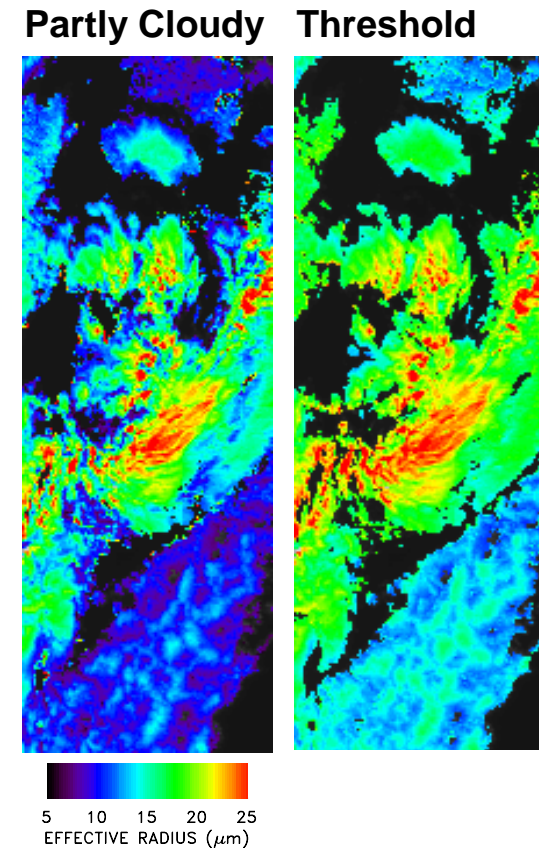
Cloud cover is overestimated.

Visible Optical Depth



Optical Depth is underestimated.

Droplet Radius

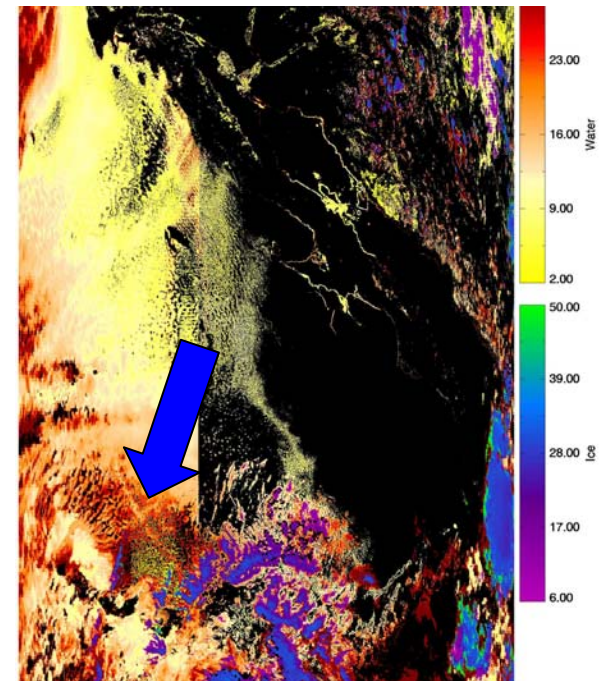
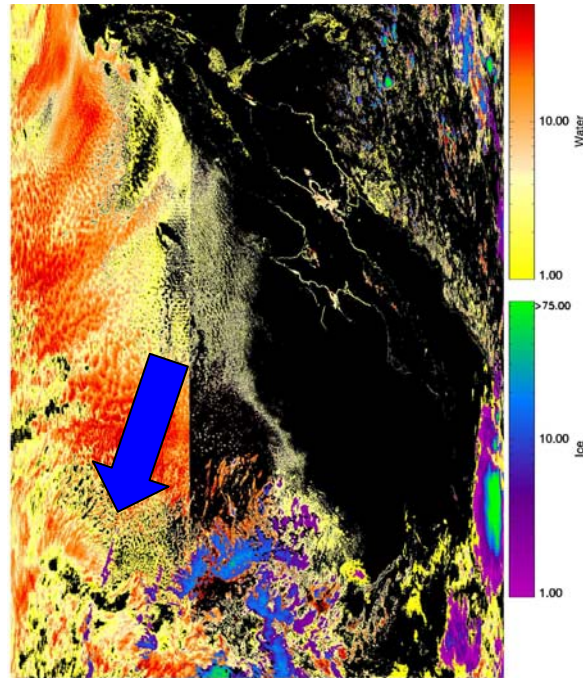


Droplet radius is overestimated.

Partly Cloudy Pixels in 1-km MODIS Retrievals

Visible Optical Depth

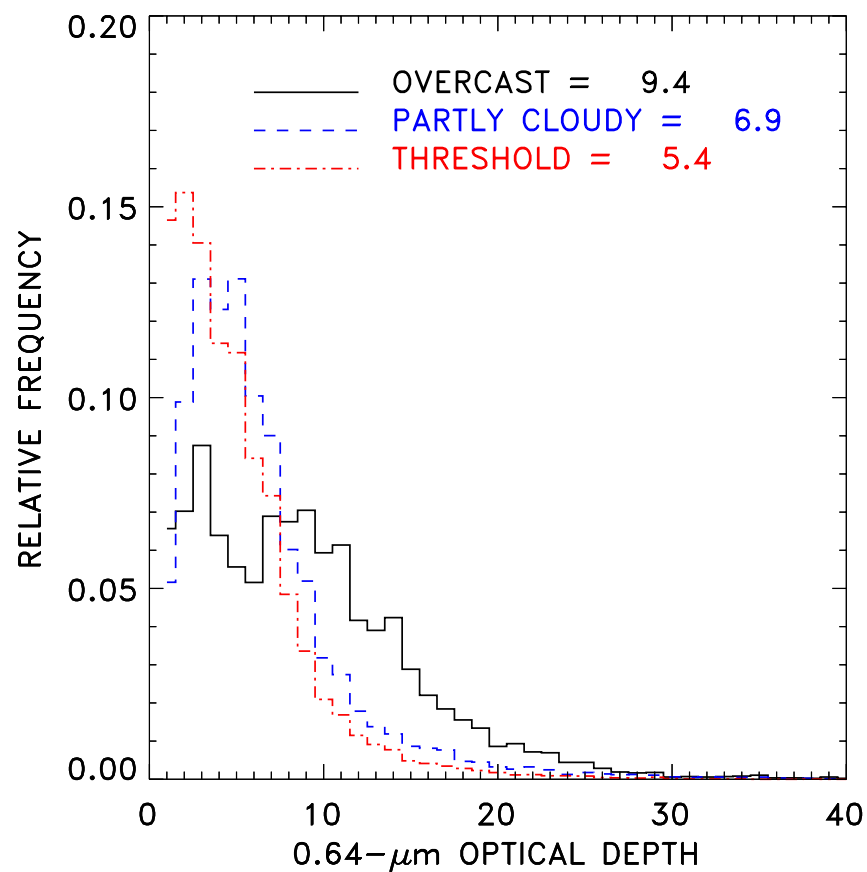
Droplet Radius



Terra 1-km MODIS data off the coast of California.

Where clouds break up, optical depths become small and droplet radii become large.

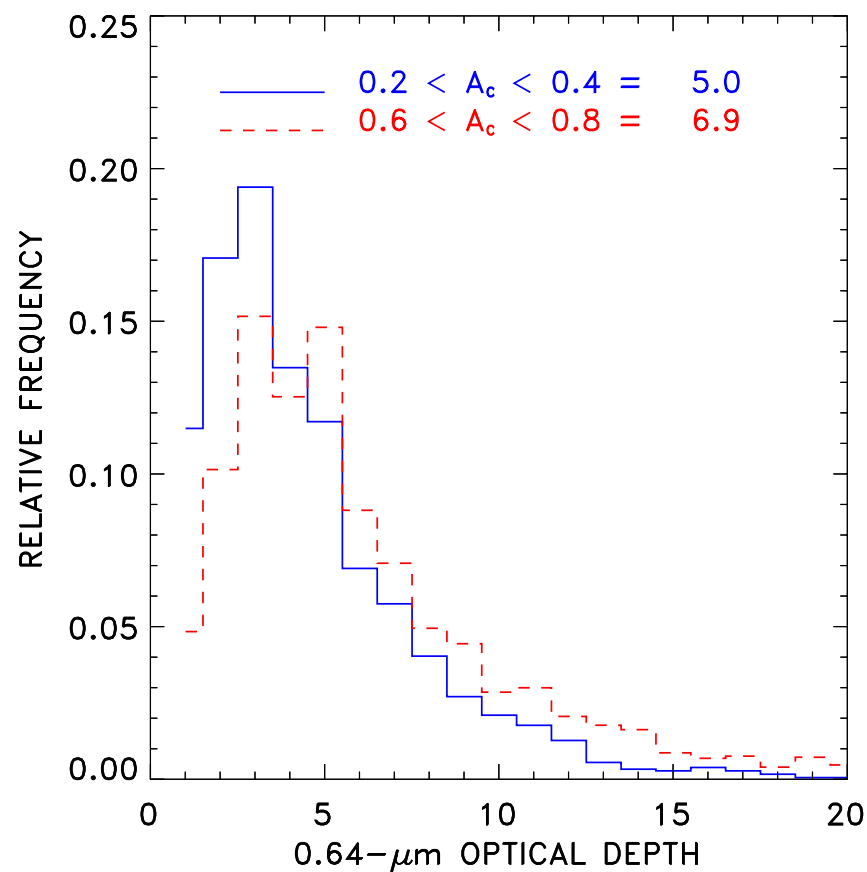
Optical Depth



Overcast pixels

Partly cloudy pixels—partly cloudy retrievals

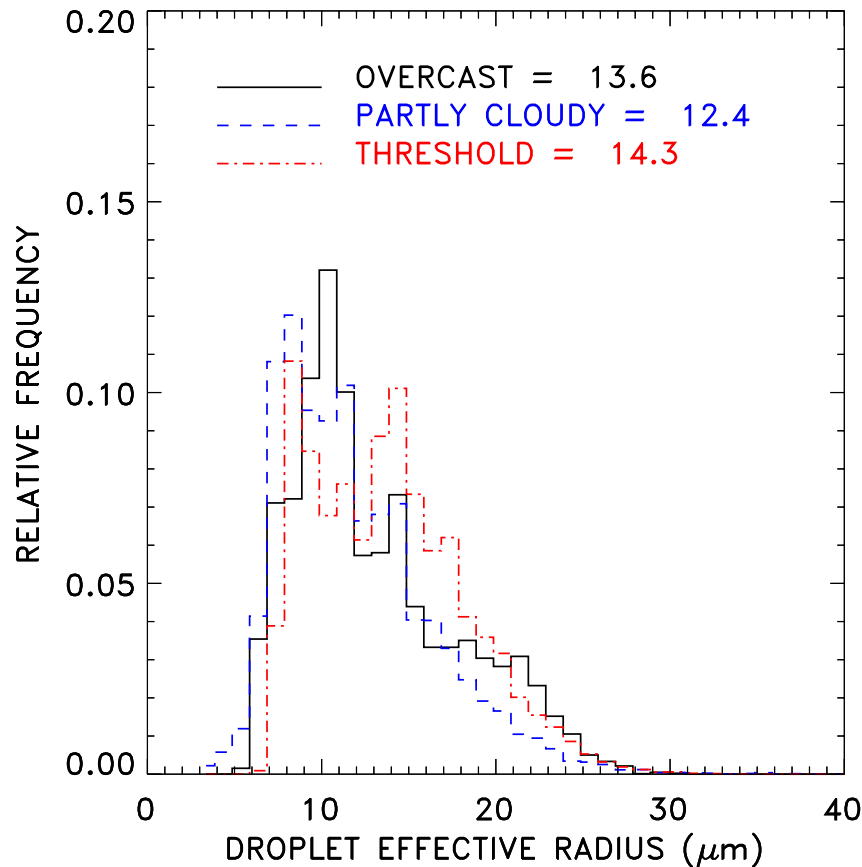
Partly cloudy pixels—threshold retrievals



Partly cloudy pixels—partly cloudy retrievals

Optical depth is almost an intrinsic property of the clouds.

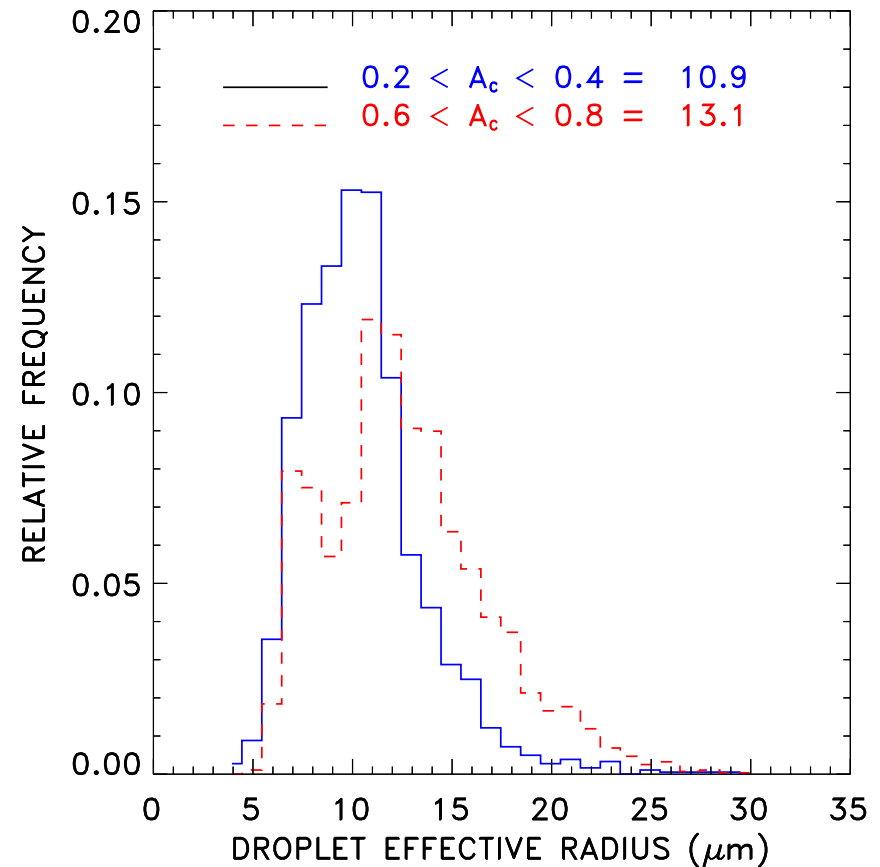
Droplet Radius



Overcast pixels

Partly cloudy pixels—partly cloudy retrievals

Partly cloudy pixels—threshold retrievals



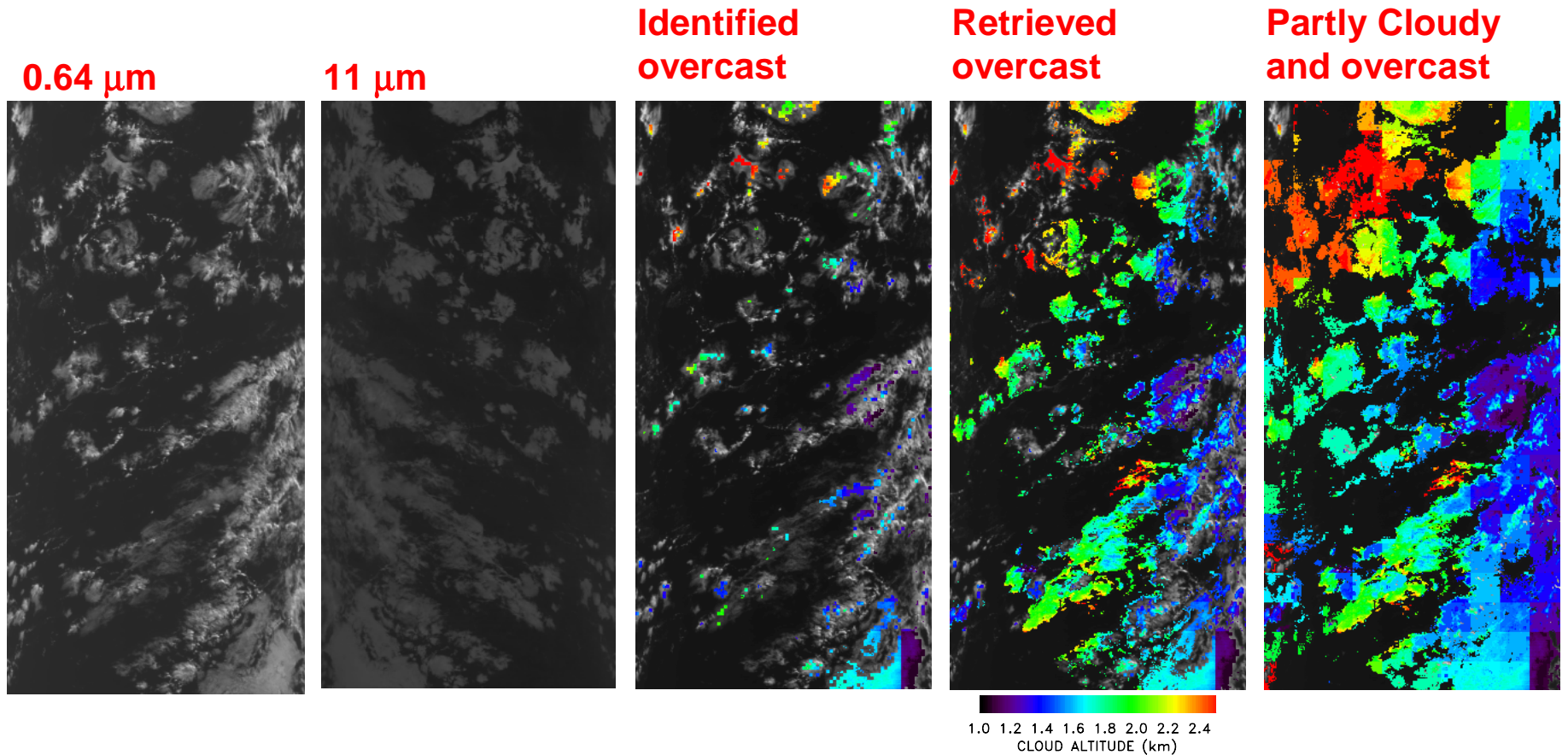
Partly cloudy pixels—partly cloudy retrievals

Droplet radius is almost an intrinsic property of the clouds.

What's New?

- **Objective analysis of cloud layer altitude.**
- **Assessment of uncertainties in retrieved properties.**
- **Sensitivity of retrieved properties to spatial resolution.**

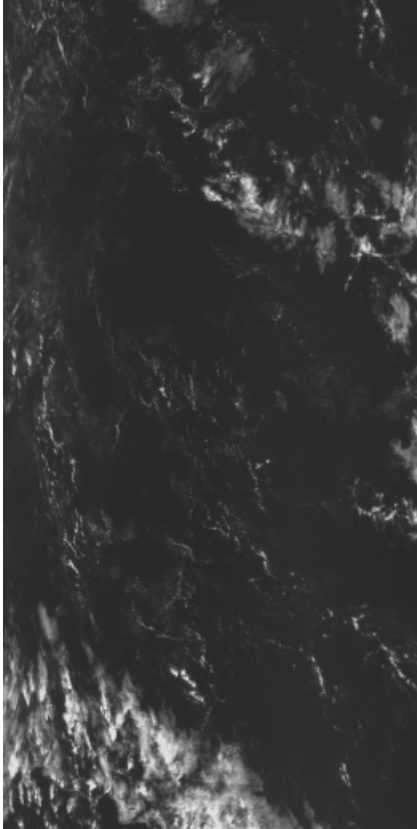
Layer Altitude



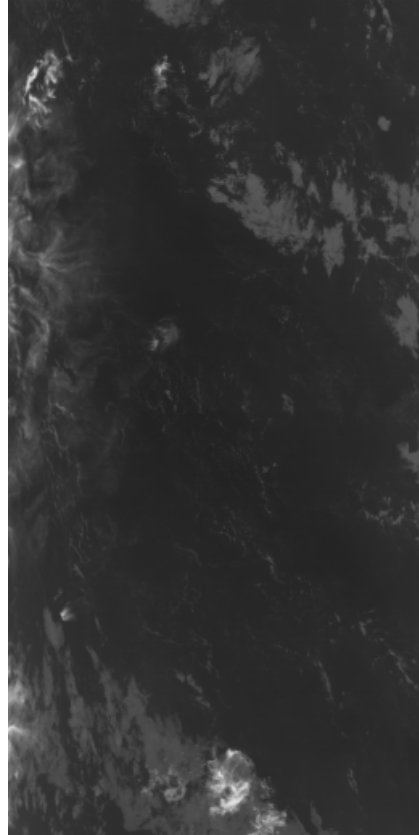
2-km VIRS imagery, 720×1100 km, off west coast of South America

Overcast Bias

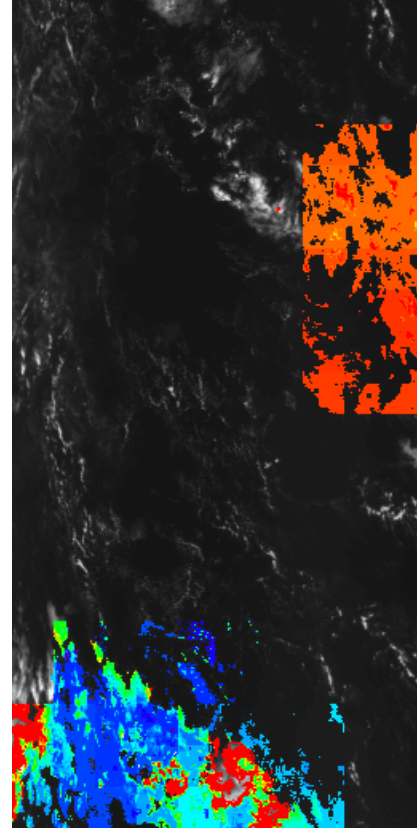
0.64 μm



11 μm



Partly Cloudy
and overcast

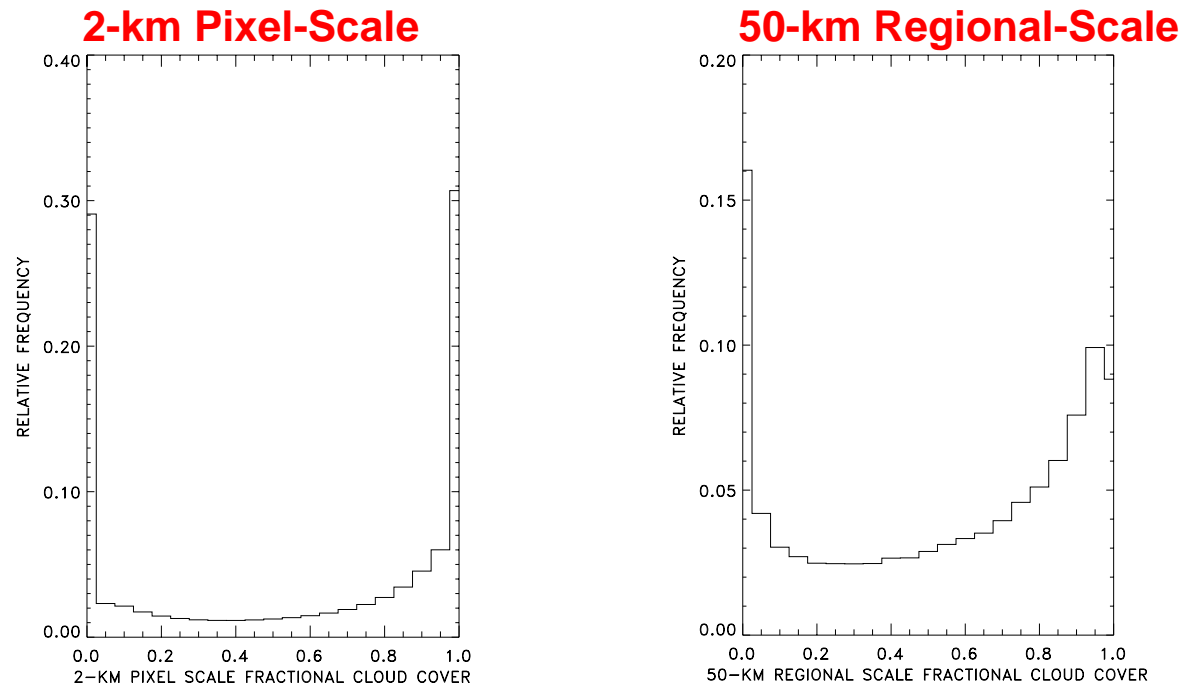


Regions that are largely cloud-free lack sufficient numbers of overcast pixels to allow determination of cloud layer altitude.

1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
CLOUD ALTITUDE (km)

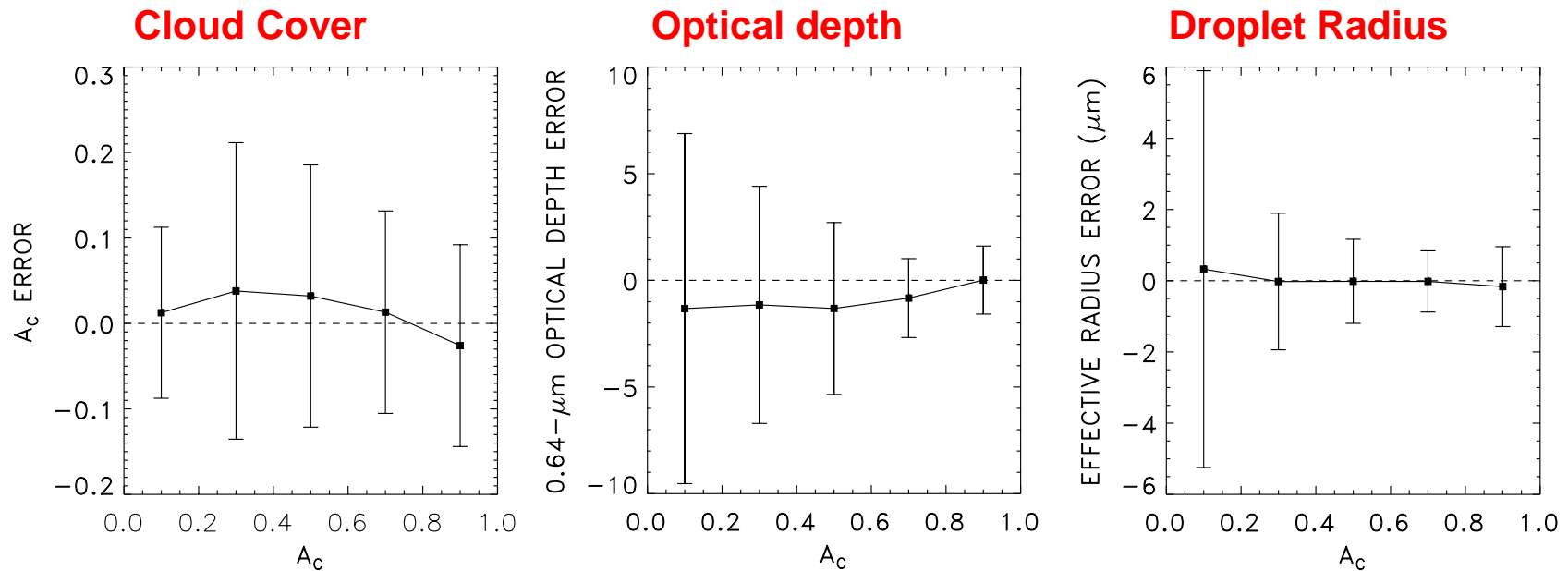
2-km VIRS imagery, 720×1100 km, off west coast of South America

Frequencies of Pixel-Scale and Regional-Scale Cloud Cover Fraction



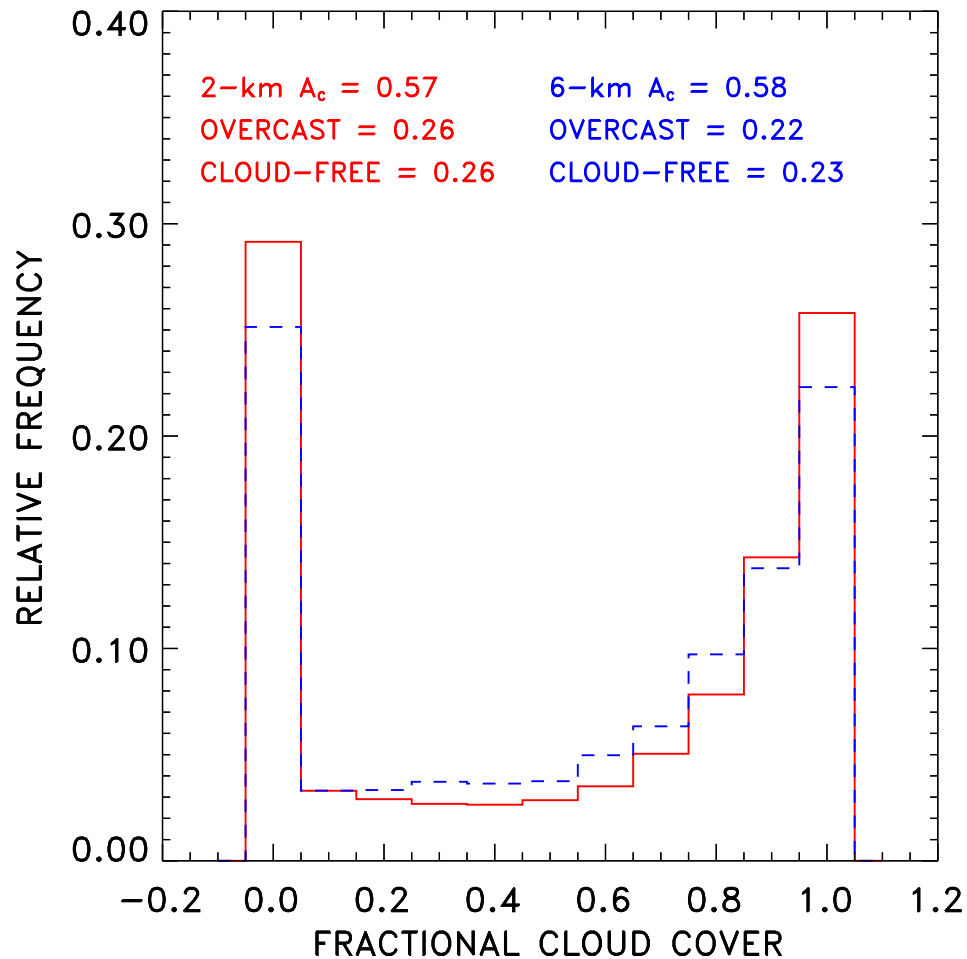
- **VIRS TRMM data for February 1998. 50-km scale ocean regions that are either cloud-free or contain a single-layered, low-level cloud system.**
- **Of the 2-km pixels, approximately 30% are cloud-free, 30% are overcast and 40% are partly cloudy.**
- **Clouds cluster: clouds group to form extensive regions that are either cloud-free or overcast.**

Sensitivity to Uncertainties in Cloud-free Radiances and Cloud Layer Altitude



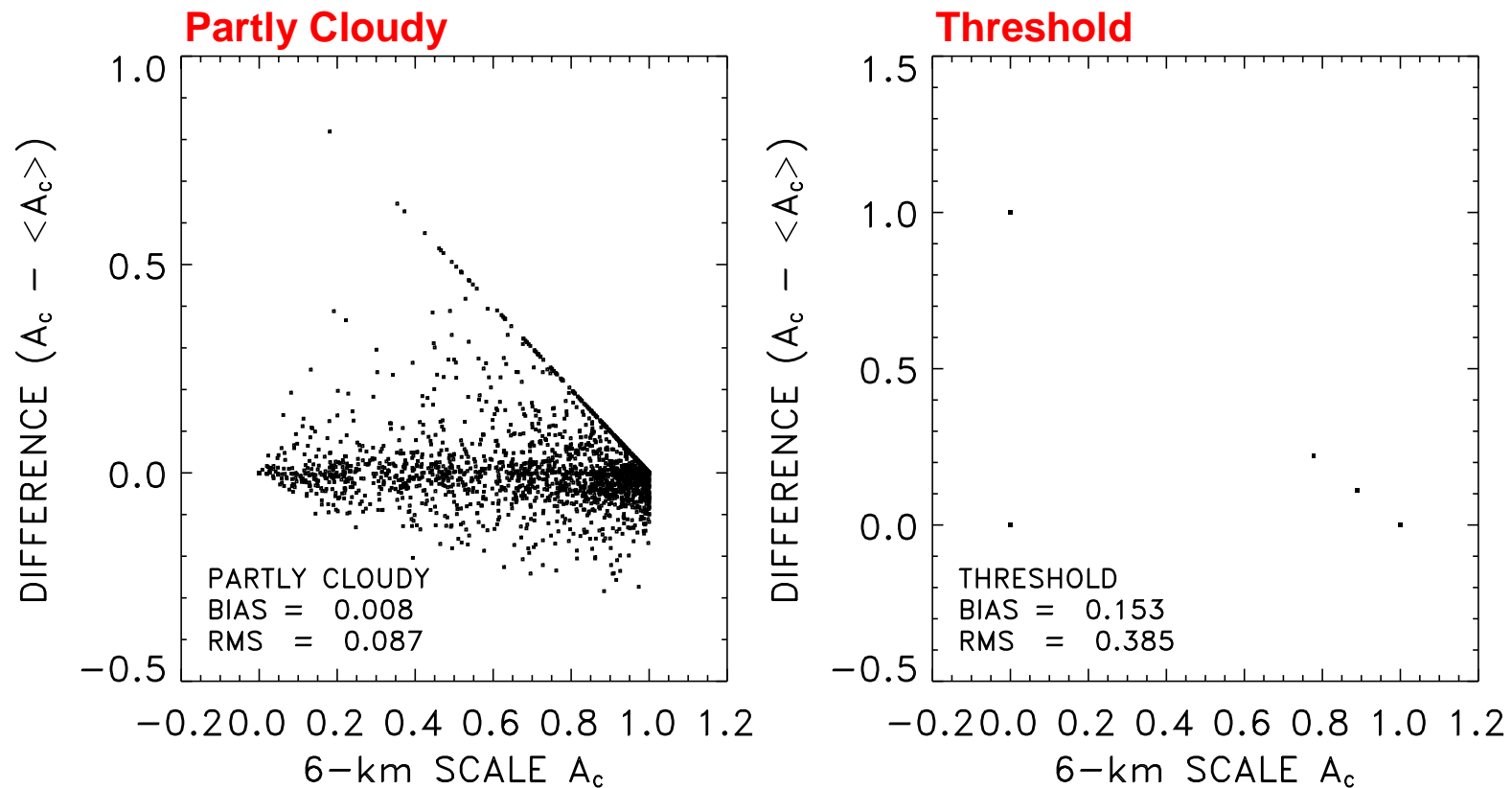
- Errors due to representative variations of surface temperature (0.4 K), cloud-free 0.64- μ m reflectance (0.002), and cloud altitude (100 m) for 50-km scale region.
- Biases due to physical constraint, $0 \leq A_c \leq 1$.

Sensitivity to Spatial Resolution



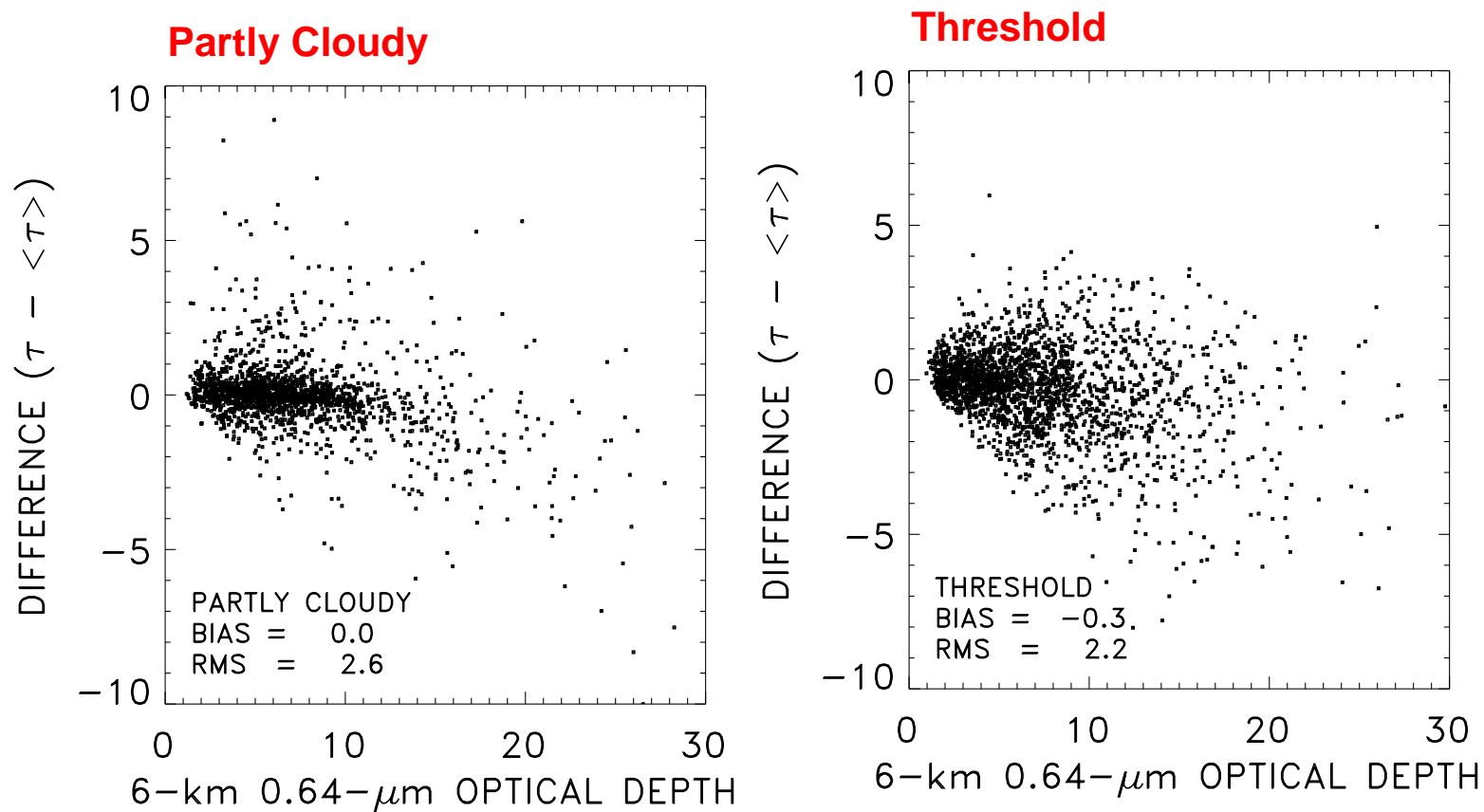
- 2-km VIRS radiances averaged to 6-km, 3×3 arrays of pixels.
- Properties retrieved using 6-km radiances compared with average properties retrieved for 2-km radiances.
- Cloud fraction for threshold retrievals 0.68 at 2 km and 0.72 at 6 km.

Sensitivity to Spatial Resolution: Pixel-Scale Cloud Fraction



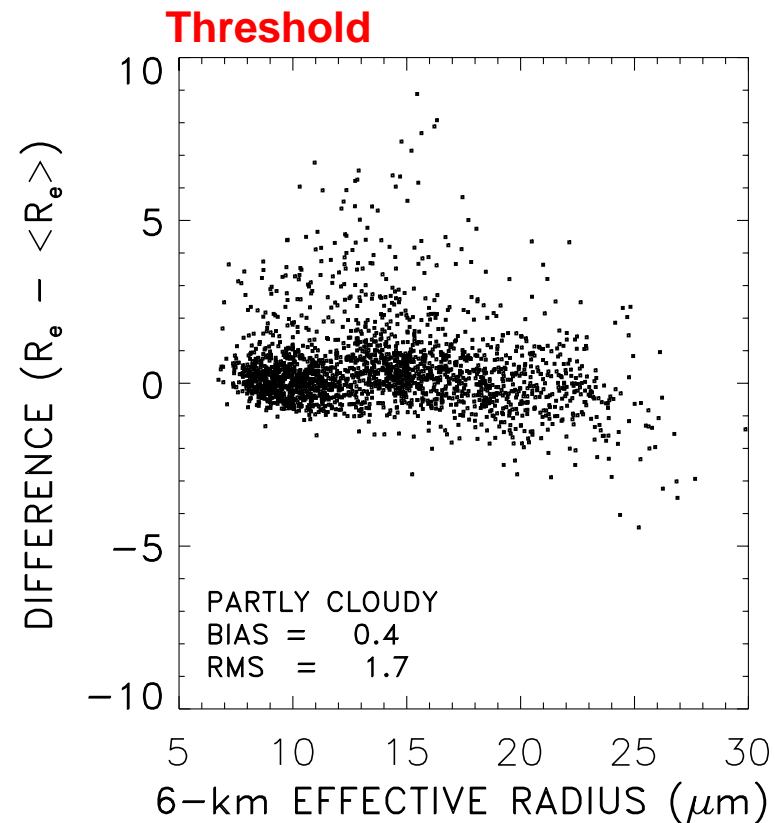
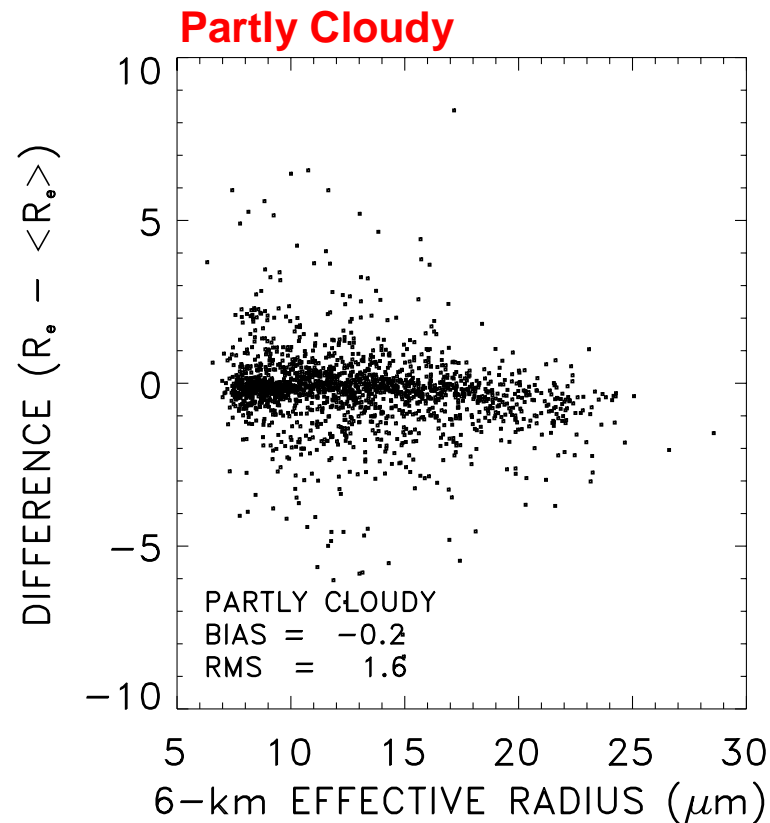
Threshold overestimates cloud fraction obtained using observations at higher spatial resolution.

Sensitivity to Spatial Resolution: Pixel-Scale Visible Optical Depth



Threshold underestimates optical depth obtained using observations at higher spatial resolution.

Sensitivity to Spatial Resolution: Pixel-Scale Droplet Effective Radius



Threshold overestimates effective radius obtained using observations at higher spatial resolution.

Conclusions

- **Threshold derived cloud properties are generally biased in ways that were expected: cloud cover and droplet radius are overestimated, optical depth, cloud liquid water, and cloud altitude are underestimated. Biases are obtained for both pixel and regional scales.**
- **Partly cloudy pixel retrievals are also biased: Pixel-scale cloud cover overestimated (< 0.05) and optical depth underestimated (< 1). Droplet radius shows little bias. Regional scale biases are negligible.**
- **Clouds cluster: most cloud-free and overcast pixels come from extensive regions (10 – 50 km) that are either cloud-free or overcast. 40% of 2-km pixels over oceans are partially cloud covered.**
- **Optical depth and droplet radius decrease as pixel-scale cloud cover decreases, but the decrease is slight and these properties are almost intrinsic to the clouds.**
- **Unlike threshold retrievals, partly cloudy pixel retrievals are relatively insensitive to the spatial resolution of the pixel.**

What's Next?

- **Compare viewing geometry dependence of retrieved properties for partly cloudy and overcast pixels. Are differences expected for the angular dependence of reflected sunlight detectable?**
- **Objectively determine limit to which estimates of layer altitude can be extended into regions that lack overcast pixels.**